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Economic analysis of greenhouse gas emissions in the Spanish economy

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ABSTRACT

The volume of greenhouse gas (GHG) emissions (carbon dioxide, methane and nitrous oxide) to the atmosphere generated by Spain's economic activity is calculated by applying an Input–Output model. The research takes the Social Accounting Matrices for Spain over the years 2002–2007 (SAMESP) as a starting point, from which emission vectors are obtained for each of these years. The results show that the main sectors by volume of emissions are "Electric power and heating", "Transport", and "Agriculture, Stockbreeding, Forestry and Fishing". The values of the emissions calculated with the vectors obtained from SAMESP are very similar to those of the emissions finally registered. Emission vector values diminished in most sectors during the period considered, particularly with respect to the "Electric power and heating" sector in the case of carbon dioxide production. The "Agriculture, Stockbreeding, Forestry and Fishing" sector was an exception to the fact because a trend for decreased emission was not recorded for any of the gases. From the calculated vectors, we estimate that the 20% reduction of GHG emissions required of countries in the EU-27 by 2020 will be accomplished by reducing carbon dioxide emissions, even though emissions of methane and nitrous oxide are likely to increase.

Contents

1. Introduction 6032
2. Methodology and database 6033
3. Results and application 6034
4. Conclusions 6036
Appendix 6039
References 6039

1. Introduction

The energy sector plays an important role in the economic growth of a country and in the living standards of its citizens. Nevertheless, in the European Union (EU-27), this sector is responsible for nearly 80 percent of the greenhouse gas (GHG) emissions to the atmosphere.[1] Therefore, it is necessary to develop an energy sector that meets two objectives at the same time: on the one hand, to supply society's energy needs and, on the other, to promote the use of technologies that are environmentally friendly.

In the case of Spain, energy transformation–mostly through combustion activities–and, to a lesser extent, the fugitive emissions from fuel,[2] represent 77.0 percent of the total GHG emissions.[3] However, there are other important processes that need to be taken into account, such as those carried out in the "Agriculture, Stockbreeding, Forestry and Fishing" and the Industry sectors, which are responsible for 10.5 percent and 7.3 percent, respectively, of the total GHG emissions.[4] In this context, the

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[1] European Environment Agency (EEA, [8]).

[2] Fugitive emissions are generated in the process of extracting, storing and manipulating solid fuels (coal) and extracting, storing, transporting, transforming or eliminating fuels derived from oil or natural gas.

[3] Ministry of the Environment and Rural and Marine Affairs–MARM-(2011).

[4] Appendix A of the Kyoto Protocol [28] considers six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6).

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objective for 2020 fixed by EU Directive 2003/30/EC is assessed here with respect to Spain. The objective of this policy is to contribute in a more efficient manner to the following targets: (1) to reduce GHG emissions by 20%, (2) to achieve a 20% participation of renewable energy sources in primary energy and (3) to increase energy efficiency by 20%.

It is possible to calculate GHG emissions for Spain by using an Input–Output (I–O) methodology. This methodology is supported by an extensive literature, since the externalities generated by production activities were long ago presented in an I–O analysis by Leontief [16]. This model has been subsequently used by a large number of authors, among which Proops et al. [22] made a comparative study of Germany and the United Kingdom; Hawdon and Pearson [11] studied economic policies in relation to energy consumption, environmental impact, employment and economic well-being; Machado et al. [18] analysed the impact of international trade on carbon dioxide (CO_2) emissions; Wiedmann et al. [31] described a series of models to evaluate environmental impacts; Limmeechokchai and Suksuntornsiri [17] analysed the relation between energy consumption and emissions; and Okushima and Tamura [21] evaluated the effect of technological change on CO_2 emissions. Finally, Cellura et al. [4,5], used Structural Decomposition Analysis to determine environmental impacts due to real production and consumption patterns and the impact that final demand has on CO_2 emissions.

In Spain, similar studies using an I–O methodology have been carried out, for example, by Alcántara and Roca [1] to estimate energy demand and CO_2 emissions. Labandeira and Labeaga [15] obtained the intensities of energy-related CO_2, while Sánchez-Chóliz and Duarte [25] assessed Spanish exports and imports in terms of direct and indirect emissions of CO_2. Rodríguez et al. [24] used the Environmental Social Accounting Matrix to analyze economic and environmental efficiency by calculating multipliers, breaking them into direct, indirect and induced. Roca and Serrano [23] analyzed the relationship between income growth and pollution using a structural decomposition analysis, while Butnar and Llop [2] quantified changes in the levels of GHG emissions due to changes in final demand for production activities. Tarancón and Del Rio [27] on the other hand analyzed links between the production sectors and emissions of CO2, while Duarte et al. [7] studied links between income levels, patterns of consumption and CO_2 emissions. Guerra and Sancho [10] used the hypothetical extraction method for measuring the energy efficiency of the economic sectors and GHG emissions. At a regional level, Manresa and Sancho [19] estimated CO_2 emissions for the Catalan economy, while Cardenete et al. [3] carried out a similar study based on the Andalusian economy.

Although estimates have been made based on the I–O methodology, and therefore using the Leontief inverse matrix, the model used here to calculate the emission vectors takes SAM as its database to obtain estimates compatible with future research involving residential sector emissions included in the SAM and not in the I–O table.

The first objective of this article is to calculate emission vectors from a Social Accounting Matrix for Spain (SAMESP), in which each element represents the volume of emissions of each production sector by monetary unit. An emission vector is calculated for each GHG considered (CO_2, methane (CH_4) and nitrous oxide (N_2O)). The results permit identification of those economic sectors with a lower intensity in relation to GHG emissions, i.e. those that produce a greater volume of emissions per monetary unit. These data can facilitate the design of future energy policies oriented towards efficiency and the improvement of the environment.

The paper also verifies the predictive character of the emission vectors by comparing the calculated emission values with those actually observed. For this purpose, the vectors obtained for the years 2002–2007 are used to estimate the vector for the year 2009 and to compare this with the observed emissions for that year according to the GHG Emissions Inventory. This article thus contributes to the literature by testing the robustness of the implemented methodology.

Once this is verified, we can estimate the minimum technological improvement required by the Spanish economy to satisfy Directive 2003/30/EC commitments. This is the second objective of this article. In this sense, the article also contributes to the literature given that no such similar analysis has been made for the Spanish case.

To perform this emission analysis we have used a Social Accounting Matrix (SAM) at purchase prices for Spain in the years 2002–2007 classified according to activity division, and built from the supply and use tables of the I–O Framework and the Accounts Charts provided by the Instituto Nacional de Estadística [12,13]. In addition, we have used statistical data on emissions taken from the GHG Emissions Inventory elaborated by the Ministry Of The Environment And Rural And Marine Affairs (MARM) [20] and the Secretariat of the United Nations Framework Convention on Climate Change [29].

The article is structured into four sections. Following this introduction, both the database used in the analysis and the methodology employed to calculate the emission vectors will be described. In the Section 3, we will show the results obtained by implementing this methodology and illustrate an application of those results, while in the Section 4, the conclusions of the study will be presented.

2. Methodology and database

The SAMs initially introduced by Stone [26] are used as a statistical support for the construction of economic models that aim to evaluate the results derived from the application of specific economic policies, among other aspects. SAMs permit all the interactions between the different production sectors to be identified, and between these and the primary factors and economic agents involved through to the final demand, thus offering a clearer picture of the economy as a whole.

A SAM is represented by a square matrix that shows all monetary flows originating from the transactions made between the production sectors and the remaining economic agents (households, non-profit sector, public sector and foreign sector). Each cell is denoted as $t_{i,j}$, with each transaction having its own row and column within the matrix. Rows and columns must be arranged identically. In a SAM, each account is represented by one row (i) and one column (j), and by convention the rows represent employment and the columns, resources. Thus, each $t_{i,j}$ cell that is not null reflects the value of all the transactions made during the period considered by the agents of sectors i and j in which agent i received payments made by agent j.

The structure of the SAM for Spain (SAMESP) is given in Table A1 of the Appendix; it includes 28 accounts, twelve of which correspond to production activities. Two production factors are also contemplated: Labour (13) and Capital (14). The latter includes Gross Operating Surplus (GOS) and Gross Mixed Income (GMI). Together with these are included Gross Capital Formation (16), which represents Savings/Investment, and twelve accounts that represent institutional sectors (households, non-financial companies, financial institutions and public administrations). Households are included within the Consumption account (15). Public administrations are represented in the following accounts: Social Security contributions paid by employers (20), Social Security contributions (21), Indirect taxes on production and

imports net of subsidies (22, 23 and 24), Trade and transport margins (25), Income tax and other current taxes (26), and Public administration expenditure (27). The foreign sector is represented by Imports/Exports (28). The three remaining accounts are the Employment and resources of non-financial companies and financial institutions (17), Property revenues (18) and Transfers (19), where social subsidies other than transfers in kind or other current transfers are included.

The information required for the construction of SAMESP is taken from the supply and use tables at basic prices of the I–O Framework for Spain and from the Accounts Charts for those same years. From the supply and use tables it is possible to obtain, by using different procedures, the technical coefficient matrix and, from this, a symmetric table. The transformation can be based on several assumptions, which in the present case is based on the sales structure to transform the supply and use tables to symmetric industry by industry input–output tables [9].

As previously pointed out, one characteristic of the I–O models is their extreme versatility, enabling them to be used in very different types of studies. Among other uses, they can serve as a basis for the analysis of the relation between production activities and GHG emissions. For each specific technology, there must be a direct relation between the production of the various sectors and the volume of emissions. On the other hand, given that the various economic sectors use different technologies, GHG emissions for the same volume of production will necessarily vary between the different sectors. Therefore, it is possible to calculate the volume of emissions by monetary unit for each of the production sectors of an economy. This is what we call the "emission vector", which allows the analysis of variations in GHG emissions under different assumptions: changes in the final demand, changes in technology, changes in environmental policies, etc.

As mentioned above, the basis of the methodology applied in this work can be found in the Leontief model. The fundamental equation of this model indicates that each sector's production depends on the final demand and on the so-called "Leontief inverse matrix", and is defined by the following expression:

$$X = [I-A]^{-1} D \tag{1}$$

where X is a column vector (nx1) representing the production of each sector, and I is the identity matrix (nxn). A is the matrix of technical coefficients, and D is a column vector (nx1) representing the final demand of each sector, including the household final consumption, investment, government spending and exports. In the case of the components of final demand, values have been deflated to year 2000 prices [6].

Since a direct relation between production and GHG emissions can be defined, it is also possible to calculate, for each production sector, the emissions per monetary unit–i.e. the emission vector. If we denote the volume of emissions generated by each of the production sectors as E and the emission vector as K, we can reformulate Eq. (1) as

$$E = \widehat{K}[I-A]^{-1} D \tag{2}$$

where $\widehat{K}$ is a diagonal matrix,[5] in which the diagonal elements correspond to those of the emission vector. The previous expression indicates that GHG emissions will depend on the final demand and on technology A. Eq. (2) may be reformulated as

$$\mathrm{E} = \widehat{K} X \tag{3}$$

from which

$$K = \widehat{X}^{-1} E \tag{4}$$

The diagonal elements of this matrix will be the elements of the emission vector.

3. Results and application

For the calculations performed, we used data derived from the Leontief inverse matrix and the final demand data obtained from SAMESP corresponding to the years 2002–2007. The latter data includes final household consumption, investment, public expenditure and exportations. GHG emissions data were taken from the GHG Inventory published by the Secretariat of the United Nations Framework Convention on Climate Change [29] for the same years.[6]

The application of Eq. (4) to each of the GHGs considered provides an emission vector for each gas, as reflected in Tables 1–3. Each of these elements represents the kilograms of equivalent CO_2 emitted per euro of production, showing the intensity of emissions produced per euro. The tables reflect data for the twelve economic sectors considered (plus the residential sector) and for three greenhouse gases (GHG)[7], CO_2, CH_4 and N_2O.[8]

In the case of CO_2, it can be seen in Table 1 that the most polluting sectors per monetary unit are "Electric power and heating", "Transport" and "Coal". In particular, electric power and heating plants are those with the highest emission coefficient, being slightly more than twice the coefficients of the "Transport" and "Coal" sectors. At the other extreme, we find "Trade and remaining services" and "Food, beverages and tobacco" as the least polluting sectors per monetary unit produced.

A comparison of the emissions per monetary unit produced between 2002 and 2007 shows that they have fallen in most sectors, except in the case of "Coal" and "Agriculture, Stockbreeding, Forestry and Fishing". In some sectors such as "Food, beverages and tobacco", "Metallurgy" and "Oil refining", a considerable decrease in relative terms has occurred. However, the impact on total emissions of the positive influence of "Electric power and heating", "Transport" and "Remaining industries and construction" sectors should be noted.

In the case of CH_4, as shown in Table 2, the sectors with the highest emission coefficients are "Coal" and "Agriculture, Stockbreeding, Forestry and Fishing". For this last-mentioned sector, stockbreeding[9] is responsible for the majority of these emissions.

For the period 2002–2007, the largest decreases were observed in the "Oil and natural gas", "Transport", "Metallurgy" and "Food, beverages and tobacco" sectors. However, the first two and, to a lesser extent the "Coal" sector as well, should be highlighted in terms of their impact on total emissions. In contrast, the largest increases were observed for "Electric power and heating" and in the "Remaining Industries and Construction" sectors. The farming sector cannot be seen to have developed a positive trend towards reduced emissions even though it is responsible for more than 87% of the total methane gas emissions from all production sectors. The reason why this occurs is because these emissions

[5] The ˆ symbol indicates "diagonalization", this being a square matrix whose diagonal elements correspond to emission vector elements. The remaining elements have a null value.

[6] See Table A.2 of the Appendix.

[7] Only three of the six primary GHGs were considered in this analysis, given that they represent more than 97 percent of the total emissions [29].

[8] The aggregation of the different categories of GHG emission sources, as well as the total emission, can be seen in Table A.3 in the Appendix.

[9] In particular, enteric fermentation (which takes place in the digestive system of bovine and ovine cattle) and the management of animal manure are responsible for 60 percent of the total methane emissions.

Table 1
CO2 emission vector by sector in Spain (2002–2007) (Kg of equivalent CO2/€).
Source: own elaboration.

	2002	2003	2004	2005	2006	2007	Variation 2002/2007 (%)
1. Agriculture, stockbreeding, forestry and fishing	0.1648	0.1607	0.1672	0.1765	0.1785	0.1700	3.1
2. Coal	0.7649	0.9320	0.9286	0.8822	0.8700	0.8570	12.0
3. Oil and natural gas	0.1528	0.1402	0.1390	0.1021	0.0899	0.1022	−33.1
4. Oil refining	0.3261	0.3153	0.3008	0.2430	0.2149	0.2092	−35.8
5. Electric power and heating	3.5029	3.1260	3.2575	2.9510	2.4622	2.4396	−30.4
6. Food, beverages and tobacco	0.0562	0.0579	0.0557	0.0525	0.0566	0.0311	−44.6
7. Paper and printing	0.1382	0.1675	0.1516	0.1538	0.1492	0.1343	−2.8
8. Chemical industry	0.1110	0.1198	0.1257	0.1182	0.1117	0.1021	−8.0
9. Metallurgy	0.1813	0.1681	0.1691	0.1713	0.1469	0.1162	−35.9
10. Remaining industries and construction	0.1090	0.1101	0.1072	0.1037	0.0946	0.1015	−6.9
11. Transport	1.3805	1.3869	1.3723	1.3388	1.2959	1.2655	−8.3
12. Trade and remaining services	0.0139	0.0146	0.0142	0.0142	0.0120	0.0113	−18.7

Table 2
CH_4 emission vector (2002–2007) (Kg of equivalent CO_2/€ Note: To transform methane gas emissions (expressed in units of mass of the gas itself) in mass units of CO2 equivalent, has been multiplied by a conversion factor of 21. Thus, 1 kg of methane is 21 kg CO2 equivalent.).
Source: own elaboration.

	2002	2003	2004	2005	2006	2007	Variation 2002/2007 (%)
1. Agriculture, stockbreeding, forestry and fishing	0.3292	0.3286	0.3312	0.3420	0.3452	0.3323	0.9
2. Coal	0.4421	0.4903	0.4451	0.4045	0.4220	0.3927	−11.2
3. Oil and natural gas	0.0668	0.0493	0.0514	0.0423	0.0232	0.0216	−67.7
4. Oil refining	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001	−32.9
5. Electric power and heating	0.0013	0.0020	0.0028	0.0027	0.0027	0.0026	96.8
6. Food, beverages and tobacco	0.0007	0.0007	0.0007	0.0008	0.0010	0.0004	−41.0
7. Paper and printing	0.0015	0.0019	0.0015	0.0017	0.0017	0.0014	−10.1
8. Chemical industry	0.0016	0.0018	0.0020	0.0020	0.0020	0.0017	10.2
9. Metallurgy	0.0008	0.0009	0.0010	0.0011	0.0009	0.0004	−47.2
10. Remaining industries and construction	0.0003	0.0004	0.0004	0.0005	0.0004	0.0006	59.6
11. Transport	0.0032	0.0029	0.0025	0.0022	0.0019	0.0016	−48.6
12. Trade and remaining services	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	14.1

Table 3
N_2O emission vector by sector in Spain (2002–2007) (Kg of equivalent CO_2/€ Note: To transform the nitrous oxide emissions (expressed in units of mass of the gas itself) in mass units of CO2 equivalent, has been multiplied by a conversion factor of 310. Thus, 1 kg of methane corresponds to 310 kg of CO2 equivalent.).
Source:own elaboration.

	2002	2003	2004	2005	2006	2007	Variation 2002/2007 (%)
1. Agriculture, stockbreeding, forestry and fishing	0.3861	0.4064	0.3950	0.3829	0.3923	0.3826	−0.9
2. Coal	0.0051	0.0059	0.0059	0.0057	0.0058	0.0056	9.0
3. Oil and natural gas	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	−82.3
4. Oil refining	0.0026	0.0025	0.0024	0.0019	0.0017	0.0017	−36.0
5. Electric power and heat	0.0212	0.0194	0.0191	0.0170	0.0147	0.0141	−33.3
6. Food, beverages and tobacco	0.0005	0.0005	0.0004	0.0004	0.0004	0.0003	−34.4
7. Paper and printing	0.0021	0.0023	0.0023	0.0023	0.0022	0.0022	4.8
8. Chemical industry	0.0363	0.0319	0.0291	0.0310	0.0286	0.0251	−30.6
9. Metallurgy	0.0010	0.0010	0.0009	0.0009	0.0008	0.0006	−42.6
10. Remaining industries and construction	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	−5.6
11. Transport	0.0149	0.0145	0.0132	0.0126	0.0121	0.0118	−20.6
12. Trade and remaining services	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	−17.9

are largely due to the digestive processes of cattle and the management of manure.

In the case of N_2O, the "Agriculture, Stockbreeding, Forestry and Fishing" sector is responsible for more than 80% of emissions of all the production sectors. Furthermore, as shown in Table 3, this sector generates the highest emissions of gas produced per monetary unit. The evolution of N_2O emissions over recent years has barely changed, which contrasts with most other sectors where an improvement in the emission vectors is seen. In this sense, the improvement in the "Electric power and heating", "Chemical industry" and "Transport" sectors are notable.

The reliability of the methodology is verified by comparing the calculated and measured emission data. To do this, after calculating the GHG emissions vectors for the 2002–2007 period, the emission vectors for the year 2009 are estimated. To perform this estimation, the data in Tables 1–3 are taken into account. Also, some linear and nonlinear regressions are calculated to estimate the three vectors for 2009, with time used as an independent variable. The regression with the highest coefficient of determination (R2) is chosen for each estimation (see Tables A.4–A.6 in Appendix). In the case of CO_2, most of the regressions performed are linear with a high coefficient of determination. In contrast, most of the regressions in the case of CH_4 are non-linear, mostly exponential and potential types, but with a minor value of the coefficient of determination. The case of N_2O is intermediate, with half of the regressions being linear and the other half

Table 4
GHG emission vector by sector in Spain. Year 2009.
Source: wn elaboration.

SECTORS	GHG emission vector (Kg of equivalent CO_2/€)		
	CO_2	CH_4	N_2O
1. Agriculture, stockbreeding, forestry and fishing	0.1813	0.3412	0.3824
2. Coal	0.9133	0.3715	0.0059
3. Oil and natural gas	0.0643	0.0018	0.0000
4. Oil refining	0.1465	0.0001	0.0013
5. Electric power and heating	1.9780	0.0035	0.0107
6. Food, beverages and tobacco	0.0345	0.0005	0.0003
10. Paper and printing	0.1395	0.0015	0.0021
8. Chemical industry	0.1045	0.0021	0.0257
9. Metallurgy	0.1087	0.0005	0.0005
10. Remaining industries and construction	0.0931	0.0006	0.0006
11. Transport	1.2266	0.0011	0.0114
12. Trade and remaining services	0.0108	0.0001	0.0000

Table 5
Estimated and observed GHG emissions for the year 2009.
Source: United Nations [29] and own elaboration.

GHG	**Estimated emissions** (kt of equivalent CO_2)	**Observed emissions** (kt of equivalent CO_2)	**Variation (%)**
CO_2 (Carbon dioxide)	283,257	279,564	+1.3
CH_4 (Methane)	20,516	20,799	−1.4
N_2O (Nitrous oxide)	25,377	24,735	+2.6
Total	**329,149**	**325,098**	+**1.2**

nonlinear, with a high value for the coefficient of determination for most of them. The calculated regressions for each of the sectors permit the emissions vector for 2009 to be estimated for the three GHGs. The results are shown in Table 4.

The results obtained are shown in Table 5 along with real observed data from the inventory of GHG emissions [30].[10]

It should be noted that the calculated emissions differ very little from the real observed emissions, with the highest variation being in the case of N_2O. For the three GHGs considered as a whole, the difference (relative error) is +1.2% in terms of the variation with respect to each other. Some of these differences could be due to the small number of observations (6) that have been taken into account.

Once the GHG emission vector was calculated, a simulation was performed with the aim of determining whether Spain can meet the objectives established by Directive 2003/30/EC in relation to the emission levels of these three GHGs in 2020. The hypothesis considered to comply with the 2020 scenario implies that emission levels of CO_2, CH_4 and N_2O would be reduce by 20% with respect to 1990s' values. Column 3 in Table 6 shows these targets.

Column 2 in Table 6 shows the emission levels calculated from the derived vectors. To determine these we assume a linear increase of the final demand that equals the growth of the GDP between 2007 and 2009. For the years between 2010 and 2017, we use forecasts for Spain's GDP growth published by the International Monetary Fund [14]. From 2017 to 2020 the forecast for 2017 is assumed to remain constant.

[10] Before comparing the calculated values for the vectors of 2009 with the real measured emission values, the growth rates at constant prices of the final demand components in Spain (Diaz and Garcia, 2011) in 2008 and 2009 must be taken into account. These rates are: private consumption (−1.05 and −4.98%), gross capital formation (−4.71 and −16.46%), public consumption (5.37 and 2.44%) and exports (−1.54 and −12.26%). Díaz and García (2011).

Table 6
Estimated and observed GHG emissions for the year 2020.
Source: IMF (2012) and own elaboration.

GHG	**Estimated emissions** (kt of equivalent CO_2)	**Objective 2020** (kt of equivalent CO_2)	**Variation (%)**
CO_2 (Carbon dioxide)	167,210	180,652	−7.4
CH_4 (Methane)	24,123	21,816	+14.6
N_2O (Nitrous oxide)	27,394	26,363	+23.7
Total	**218,727**	**233,169**	−**2.3**

Table A1
Structure of the SAMESP.
Source: own elaboration.

	SAMESP
Productive sectors	1 al 12
Primary factors:	
Labour	13
Capital	14
Savings/investment:	
Gross capital formation	16
Institutional sectors:	
Consumption	15
Non-financial companies/financial institutions	17
Property revenues	18
Transfers	19
Social security deductions paid by employers	20
Social security contributions	21
Taxes less subsidies on products (industries)	22
Other less subsidies on production	23
Taxes less subsidies on products (final demand)	24
Trade and transport margins	25
Income tax and other current taxes	26
Public administration expenditure	27
Foreign sector:	
Imports/exports	28
Source: own elaboration	

The last row in Table 6 shows that the 2020 target could be achieved by a reduction of CO_2 emissions (the most abundant GHG), given that the estimated emissions of methane and nitrous oxide are expected to increase.

4. Conclusions

The calculation of an emission vector for three GHGs (carbon dioxide, methane and nitrous oxide) among 2002 and 2007 shows us that the two main production activities generating the largest volume of carbon dioxide per monetary unit are "Transport" and "Electric power and heating". Although the total emissions of both sectors slightly exceed 100,000 kt of equivalent CO_2, their efficiency is different with respect to emissions; in particular, in 2002 the "Electric power and heating" sector emits twice as much CO_2 per monetary unit (3.5 kg of equivalent CO_2/€) as the "Transport" sector (1.38 kg of equivalent CO_2/€). However, its evolution over the period 2002–2007 has been, in terms of emissions per monetary unit, more positive than that of "Transport".

In 2002, for the two other gases, CH_4 and N_2O, the "Agriculture, Stockbreeding, Forestry and Fishing" sector produces the highest volume of emissions with average coefficients per

Table A2
GHG emissions by sector in Spain. Years 2002–2007. GHG Emissions (kt of equivalent CO_2).
Source: UNFCCC (2011) and own elaboration.

	2002			2003			2004		
	Carbon dioxide	**Methane**	**Nitrous oxide**	**Carbon dioxide**	**Methane**	**Nitrous oxide**	**Carbon dioxide**	**Methane**	**Nitrous oxide**
1. Agriculture, stockbreeding, forestry and fishing	9,751.4	19,475.6	22,843.3	9,761.4	19,962.2	24,685.6	9,912.5	19,632.7	23,416.3
2. Coal	1,894.0	1,094.8	12.7	2,044.6	1,075.5	13.0	2,147.6	1,029.4	13.7
3. Oil and natural gas	2,051.0	896.8	0.1	1,828.9	642.9	0.1	2,087.0	772.2	0.0
4. Oil refining	12,784.8	7.2	102.9	12,708.9	7.3	102.3	13,397.9	7.6	106.8
5. Electric power and heating	98,208.1	37.5	593.9	91,093.8	57.0	564.1	100,011.0	86.3	585.0
6. Food, beverages and tobacco	5,956.2	73.8	47.8	6,276.2	80.6	50.0	6,317.8	84.9	50.4
7. Paper and printing	5,251.5	58.4	78.5	6,250.4	72.1	86.7	5,622.5	56.7	85.6
8. Chemical industry	9,993.66	141.8	3,263.9	11,028.41	163.9	2,939.3	11,849.06	185.4	2,739.7
9. Metallurgy	12,705.8	53.0	73.3	12,020.3	64.9	68.4	13,563.4	82.6	75.2
10. Remaining industries and construction	54,975.3	175.1	335.4	58,248.7	222.0	352.9	59,341.0	245.1	358.9
11. Transport	88,661.1	203.2	955.4	92,610.6	193.7	967.9	96,220.0	177.7	923.5
12. Trade and remaining services	7,881.5	40.0	39.1	8,641.7	44.6	42.2	8,892.9	49.3	43.3
Economic sectors total	**310,114.3**	**22,257.1**	**28,346.2**	**312,514.0**	**22,586.6**	**29,872.5**	**329,362.7**	**22,410.0**	**28,398.4**
Residential sector	17,308.5	12,710.2	1,361.4	18,755.9	12,753.4	1,385.4	19,531.0	12,795.5	1,396.1
Total emissions	**327,422.8**	**34,967.3**	**29,707.6**	**331,269.9**	**35,340.0**	**31,257.9**	**348,893.7**	**35,205.5**	**29,794.5**

	2005			2006			2007		
	Carbon dioxide	**Methane**	**Nitrous oxide**	**Carbon dioxide**	**Methane**	**Nitrous oxide**	**Carbon dioxide**	**Methane**	**Nitrous oxide**
1. Agriculture, stockbreeding, forestry and fishing	9,931.3	19,250.5	21,547.7	10,052.6	19,444.3	22,095.5	10,119.4	19,779.2	22,773.9
2. Coal	2,138.4	980.4	13.8	1,998.4	969.4	13.2	2,004.7	918.5	13.0
3. Oil and natural gas	2,061.6	854.7	0.1	2,188.9	564.4	0.1	2,391.6	504.6	0.0
4. Oil refining	13,091.8	7.6	103.3	12,915.5	7.4	103.9	12,849.3	7.5	103.1
5. Electric power and heating	110,061.8	99.9	634.0	101,536.5	111.3	607.8	107,499.1	116.0	622.6
6. Food, beverages and tobacco	6,062.4	93.7	49.0	6,699.1	118.6	53.3	3,788.5	50.0	36.0
7. Paper and printing	5,837.6	64.9	86.1	5,786.2	67.5	86.7	5,283.3	54.3	85.2
8. Chemical industry	11,515.55	192.7	3,022.2	11,132.80	199.0	2,849.1	10,708.78	181.9	2,636.5
9. Metallurgy	14,319.1	93.2	74.6	13,949.8	84.0	73.8	12,017.4	41.3	62.1
10. Remaining industries and construction	60,956.9	266.5	371.2	59,800.7	238.4	369.4	65,186.6	355.9	403.3
11. Transport	99,238.1	165.1	934.4	102,372.5	148.1	956.7	105,789.6	136.0	987.5
12. Trade and remaining services	9,315.3	54.7	45.2	8,351.3	57.8	40.9	8,284.9	58.9	41.5
Economic sectors total	**344,530.0**	**22,123.9**	**26,881.6**	**336,784.2**	**22,010.1**	**27,250.4**	**345,923.3**	**22,204.4**	**27,764.7**
Residential sector	19,692.1	13,222.7	1,414.1	18,130.0	13,823.2	1,401.2	18,460.1	14,369.5	1,440.7
Total emissions	**364,222.1**	**35,346.6**	**28,295.7**	**354,914.2**	**35,833.3**	**28,651.6**	**364,383.4**	**36,573.9**	**29,205.4**

Table A3
Aggregation of the different categories of GHG emission sources.
Source: Own elaboration.

Economic sectors	Categories[a]
1. Agriculture, stockbreeding, forestry and fishing	1.A.4.c. Agriculture, forestry and fishing
	4. Agriculture
2. Coal	1.A.1.c. Manufacture of solid fuels
	1.B.1. Fugitive emissions (solid fuels)
3. Oil and natural gas	1.B.2. Fugitive emissions (oil and natural gas)
4. Oil refining	1.A.1.b. Oil refining
5. Electric power and heating	1.A.1.a. Public service production of electric power and heat
6. Food, beverages and tobacco	1.A.2.e. Processing of food, beverage and tobacco
10. Paper and printing	1.A.2.d. Paste, paper and printing
8. Chemical industry	1.A.2.c. Chemical products
	2.B. Chemical industry
	3. Use of solvents and other products
9. Metallurgy	1.A.2.a. Iron and steel
	1.A.2.b. Non-iron metals
	2.C. Metallurgical production
10. Remaining industries and construction	1.A.2.f. Others
	2.A. Mineral products
11. Transport	1.A.3. Transport
12. Trade and the remaining services	1.A.4.a. Trade and institutional services
Others	
13. Residential sector	1.A.4.b. Residential sector
	6. Treatment and elimination of waste

[a] According to the nomenclature of the Common Reporting Format, United Nations [29].

Table A4
Trend estimation of the emission vector for CO_2.
Source: own elaboration.

	Regression	Coefficient of determination (R^2)
1. Agriculture, stockbreeding, forestry and fishing	$Y=0.1608e^{0.015x}$	0.4829
2. Coal	$Y=0.8252x^{0.0488}$	0.2021
3. Oil and natural gas	$Y=0.1651-0.0126x$	0.8206
4. Oil refining	$Y=0.3625-0.027x$	0.9357
5. Electric power and heating	$Y=3.718-0.2175x$	0.8912
6. Food, beverages and tobacco	$Y=0.0649-0.0038x$	0.4797
7. Paper and printing	$Y=0.1563-0.0021x$	0.1056
8. Chemical industry	$Y=0.1226e^{-0.02x}$	0.2555
9. Metallurgy	$Y=0.1975-0.0111x$	0.7612
10. Remaining industries and construction	$Y=0.1131-0.0025x$	0.6598
11. Transport	$Y=1.4282-0.0252x$	0.8968
12. Trade and remaining services	$Y=0.0156e^{-0.046x}$	0.6619

Table A5
Trend estimation of the emission vector for CH_4.
Source: Own elaboration.

	Regression	Coefficient of determination (R^2)
1. Agriculture, stockbreeding, forestry and fishing	$Y=0.3276x^{0.0195}$	0.3772
2. Coal	$Y=0.4837e^{-0.033x}$	0.5893
3. Oil and natural gas	$Y=0.0738-0.009x$	0.9196
4. Oil refining	$Y=0.0002-0.00001x$	0.9188
5. Electric power and heating	$Y=0.0015x^{0.4007x}$	0.8265
6. Food, beverages and tobacco	$Y=0.0008e^{-0.047x}$	0.0894
7. Paper and printing	$Y=0.0018e^{-0.021x}$	0.1090
8. Chemical industry	$Y=0.0017x^{0.941}$	0.4311
9. Metallurgy	$Y=0.0011e^{-0.091x}$	0.2121
10. Remaining industries and construction	$Y=0.0004x^{0.1681}$	0.4726
11. Transport	$Y=0.0035-0.0003x$	0.9976
12. Trade and remaining services	$Y=0.00007x^{0.0921}$	0.8550

monetary unit (0.33 and 0.39 kg of equivalent CO_2/€, respectively) that are much higher than those of the other sectors. The evolution of emissions from this sector over time has not improved, and the emission coefficient for the three gases considered has remained stable over the years studied.

It is also important to highlight the performance of the ‘‘Coal’’ sector, which although has the lowest CO_2 emission level, in 2002 shows a high contamination coefficient (0.76 kg of equivalent CO_2/€) and has increased 12% over the period (2002–2007). In 2002, methane emissions in this sector show a contamination coefficient of 0.44 kg of equivalent CO_2/€ although it has decreased a 11% over the period (2002–2007).

Therefore, the ‘‘Agriculture, Stockbreeding, Forestry and Fishing’’, ‘‘Coal’’ and ‘‘Transport’’ sectors are candidates for the introduction of technological improvements to bring about greater efficiency in terms of emissions released into the atmosphere. However, given the sources of methane and nitrous oxide in the ‘‘Agriculture, Stockbreeding, Forestry and Fishing’’ sector, such an improvement will be difficult to achieve. Offsetting the GHG emissions will therefore be necessary by promoting the use of renewable energy sources in production processes; this will involve the use of renewable electricity sources, heat from biomass, or biofuel use in the case of agricultural machinery. Another sector with a potentially significant reduction in emissions is likely to be the ‘‘Electric power and heating’’ sector.

The estimated emission vectors show that the 2020 target of the EU-27 countries will most likely be achieved through reductions in CO_2 emission levels given that reductions in CH_4 and N_2O emission levels are not anticipated. The reason for this is that the sectors responsible for CO_2 emissions have the capacity to incorporate technical measures to reduce emissions of this gas. However, the same cannot be said in relation to the introduction of technological improvements to reduce CH_4 and N_2O emissions. Although the methodology applied in this work is based on the I–O approach using Social Accounting Matrices instead of I–O tables, it follows fixed-coefficient technology and therefore is

Table A6
Trend estimation of the emission vector for N_2O.
Source: own elaboration.

	Regression	Coefficient of determination (R^2)
1. Agriculture, stockbreeding, forestry and fishing	$Y = 0.398e^{-0.005x}$	0.1772
2. Coal	$Y = 0.0054x^{0.042}$	0.2620
3. Oil and natural gas	$Y = 0.000007 - 0.000003 Inx$	0.7128
4. Oil refining	$Y = 0.0029 - 0.0002x$	0.9348
5. Electric power and heating	$Y = 0.0227 - 0.0015x$	0.9687
6. Food, beverages and tobacco	$Y = 0.0005 - 0.00002x$	0.4993
7. Paper and printing	$Y = 0.0023 - 0.00003x$	0.7687
8. Chemical industry	$Y = 0.0319 - 0.003 Inx$	0.5514
9. Metallurgy	$Y = 0.001 - 0.00006x$	0.7030
10. Remaining industries and construction	$Y = 0.0007 - 0.00003 Inx$	0.6057
11. Transport	$Y = 0.0143x^{-0.109}$	0.9314
12. Trade and remaining services	$Y = 0.00007 - 0.000003x$	0.7025

likely to be valid only for short term scenarios. As such, the results presented here have a higher predictive value for short periods of time no further distant than the 2020 scenario. Predicting a longer term scenario would require a different approach involving a dynamic general equilibrium or recursive model.

Appendix

See Tables A1–A6 for detail.

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